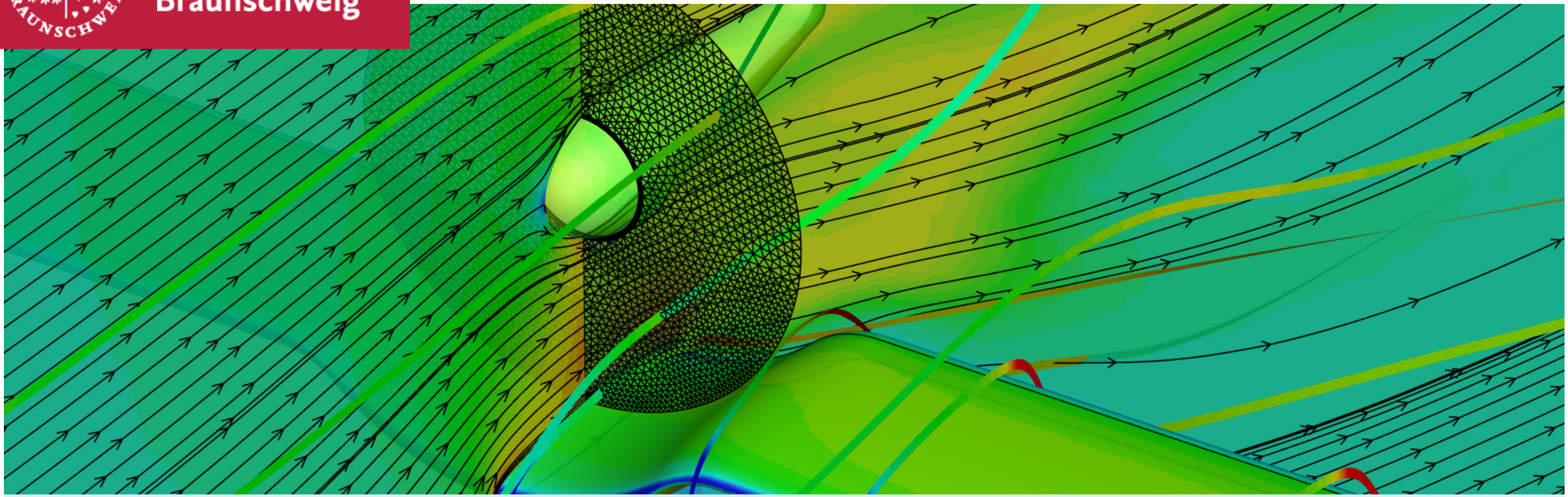
Technische Universität Braunschweig

Hochauftrieb künftiger Verkehrsflugzeuge

SFB 880



Aerodynamic and Aeroacoustic Aspects of a Channel Wing

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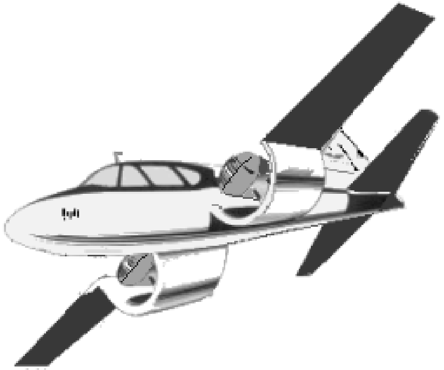
Outline

- **Introduction**
- **Test Case and Numerical Setup**
- **Comparison of configurations**
  - Aerodynamic assessment
  - Shielding capabilities
  - Influence of propeller position
- **Conclusion and Outlook**



Introduction – Motivation

Civil aviation challanges

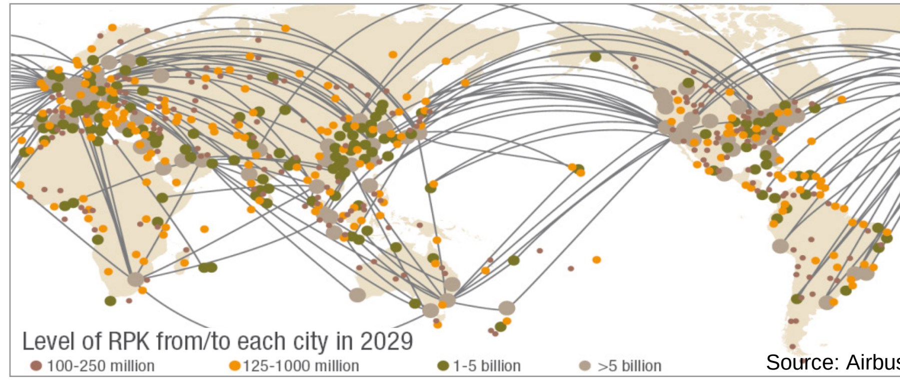
- 4.8% annual RPK growth
  (Airbus forecast 2011-2030)
- Many Hub Airports at capacity limit
- Airport extensions unpopular
  ▸ Community noise

Approach

Keep noise away from the ground

- STOL / steep climb and approach
- Shielding of engine noise

→ Smaller and less intense footprint



Introduction – Framework

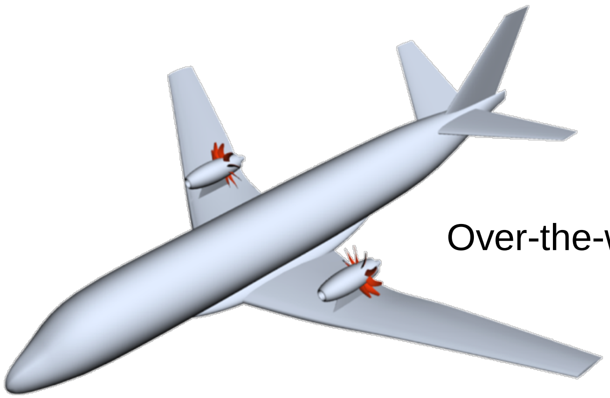
Collaborative Research Centre *SFB 880*
High-Lift for Future Civil Aircraft

- Aeroacoustics
- Aerodynamics
- Flight Dynamics

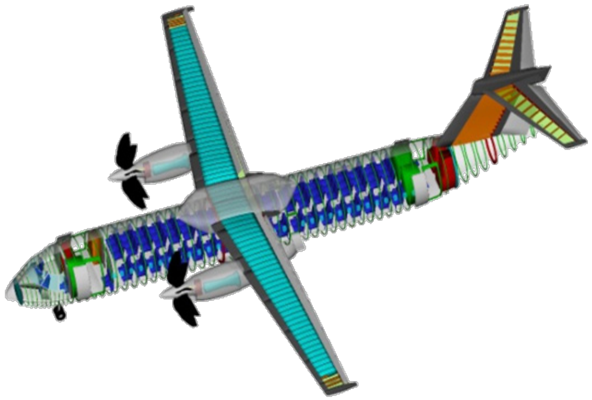
Propeller Installation

- Shielding
- Climb angle (L/D)
- Pitching Moment

STOL Aircraft	Specs
100 PAX + freight	12000 kg
Range	2000 km
Take-off distance	800 m
$C_{L,max}$ (Landing)	3.4
T/W (static thrust)	0.49



Over-the-wing propeller concept



Baseline (reference) version

Test Case and Numerical Setup

Propeller installation at takeoff configuration

Flow conditions

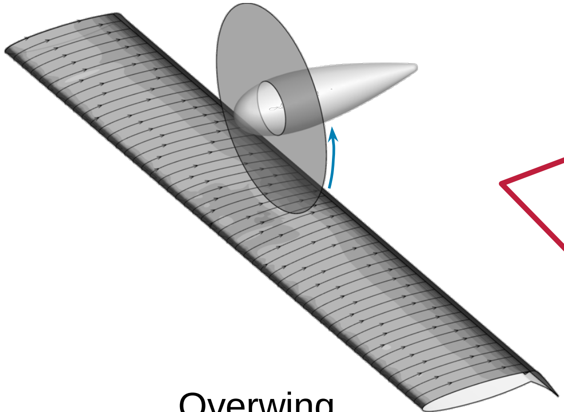
- $\mathbf{Ma_\infty} = 0.172$
- $\mathbf{Re_\infty} = 17 \cdot 10^6$
- $\alpha = 0°$ ($c_{l,TO} = 3.0$)

Airfoil

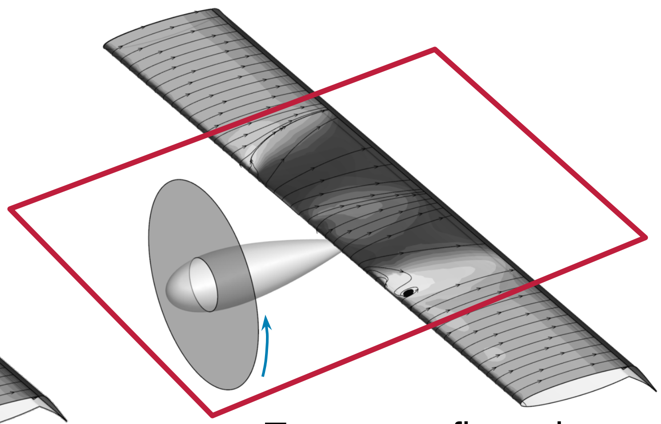
- Transonic profile (DLR-F15)
- BLC flap, $c_\mu = 0.03$

Generic propeller-wing geometry

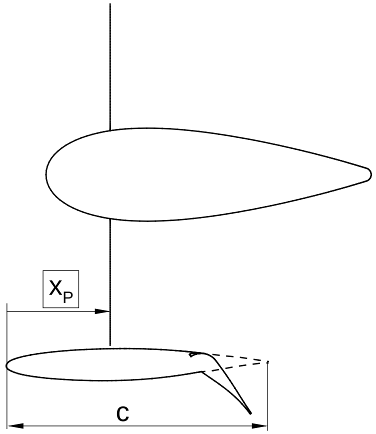
- Rectangular (unswept), no twist
- Symmetry condition at wing tips
- Actuator disk (blade element theory)
- Overwing propeller
  - Clearance $d/D_P = 0.01$
  - Axial position $x_P/c = 0.4$

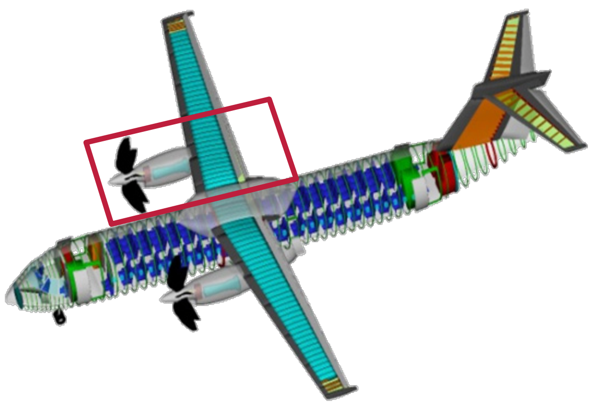


Overwing



Tractor configuration





Baseline (reference) version

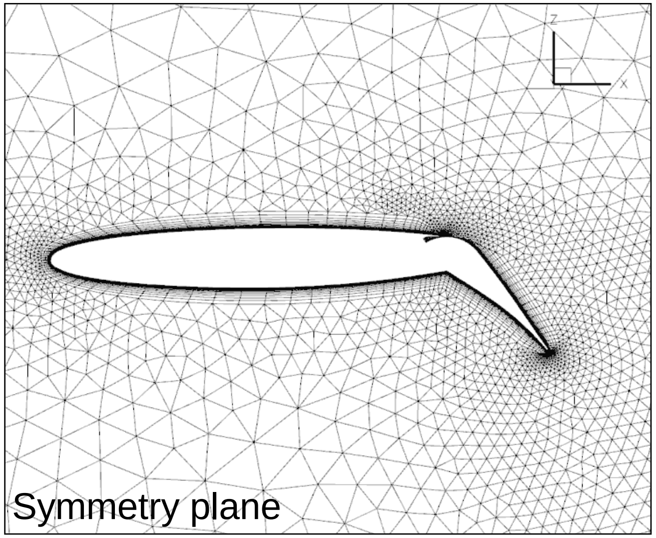
Test Case and Numerical Setup

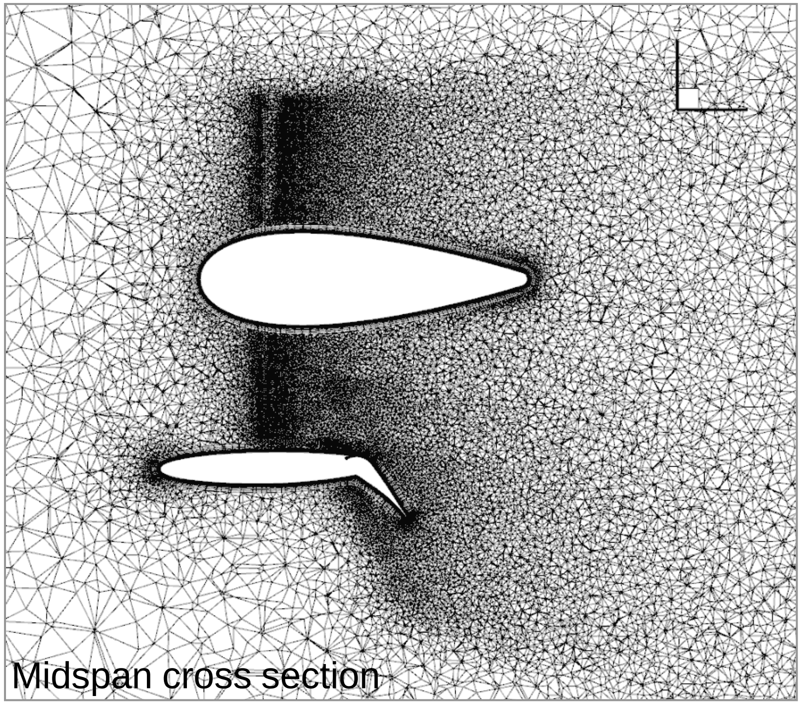
Geometry and CFD grid

- Cylindrical farfield
- Mesh size ca. 10 mil. points; $y^+ = 0{,}1 \ldots 1$

CFD method

- *DLR TAU-code*
- Steady RANS
- Spalart-Allmaras turbulence model



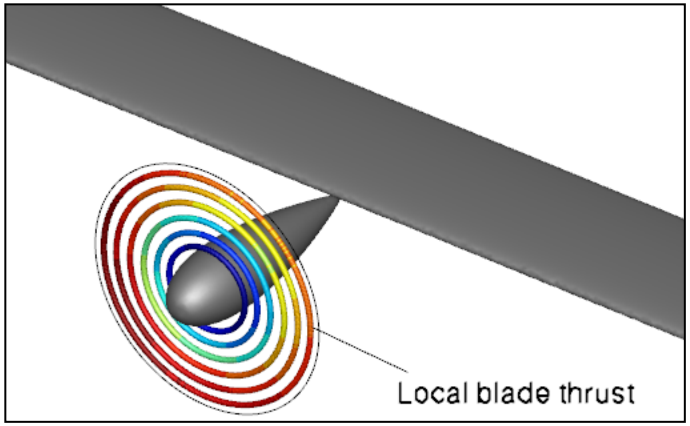


CFD grid, Centaur   Mesh refinements

Test Case and Numerical Setup

Source model (Glegg 1991, Müller 2009)

- Rings of monopoles for thickness noise
- Rings of dipoles for loading noise
- *Not yet validated*



Propeller

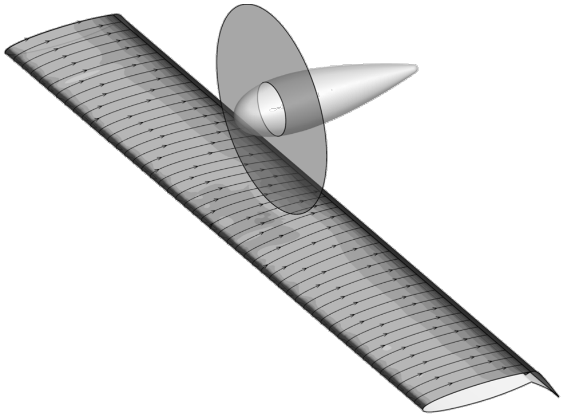
- 975 rpm, 9 blades → BPF 146 Hz
- Only dipoles for loading noise (thrust and moment)
- 6 rings on propeller disk with 360 source points ea.

Fast Multipole BEM Solver for Helmholtz equation (Lummer 2012)

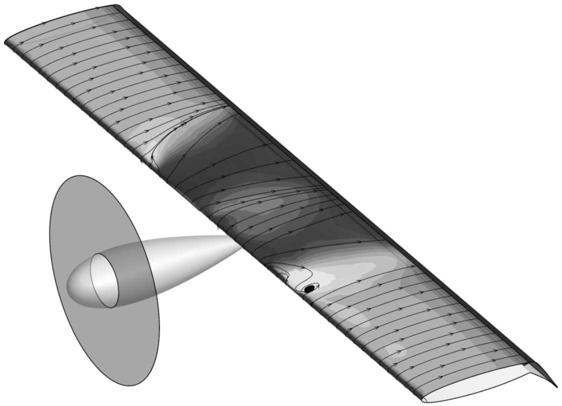
- Matrix-vector product accelerated from $O(N^2)$ to $O(N \log(N))$
- Approx. 45000 triangles, 36 points per wavelength

Results

Aeroacoustics	Aerodynamics	Flight Dynamics
Shielding	Climb angle (L/D)	Pitching Moment



Overwing configuration

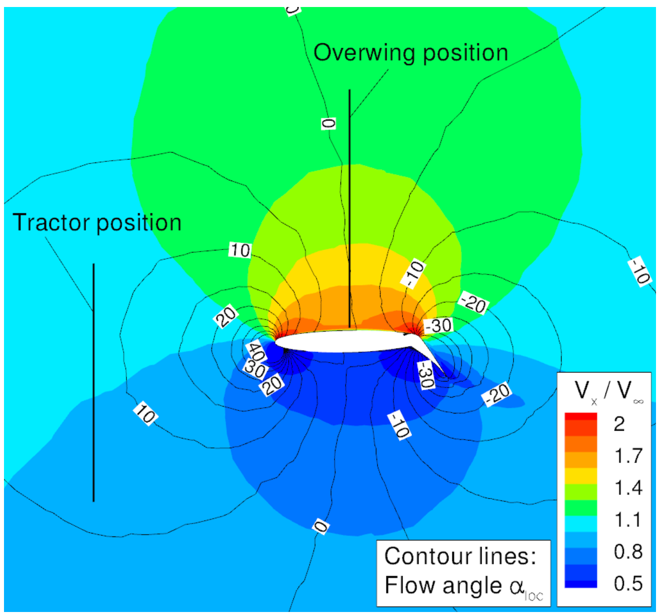


Tractor configuration

Aerodynamics – Propeller

Influence of wing flow field

- Inflow angle at tractor propeller
- Inflow velocity gradient at over-the-wing propeller

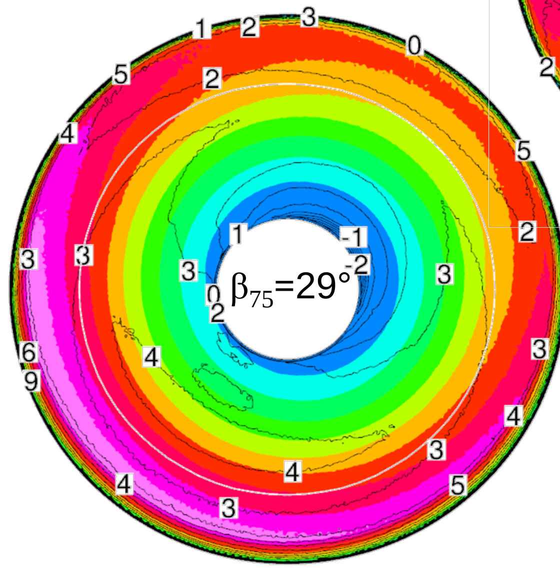


Flow field around isolated wing

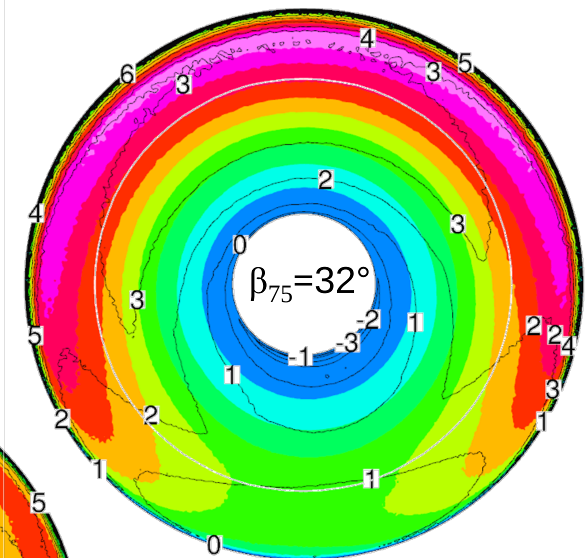
Contour plot of disk

Colour: Local thrust

Lines: Blade AOA



Tractor



Overwing

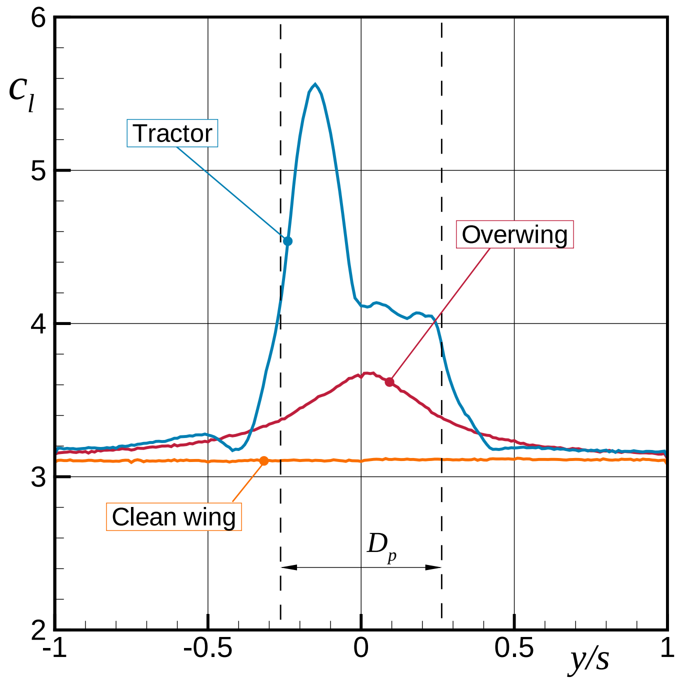
$C_{P,s}$ = const. = 0.457

20% loss in net thrust

Aerodynamics – Wing

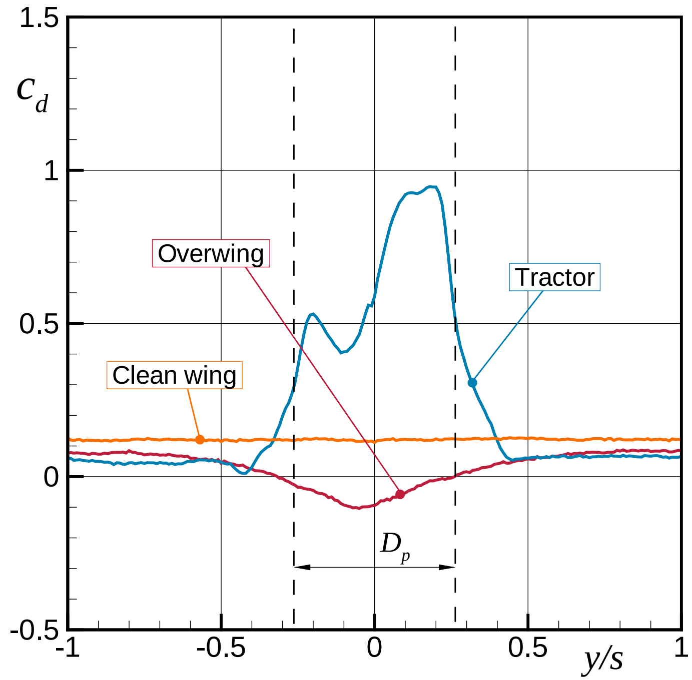
Spanwise lift distribution (rear view)

- Tractor propeller: asymmetric lift gain
  → up- / downwash due to swirl
- Overwing: symmetric, but much lower
  lift increment



Spanwise drag distribution (rear view)

- Tractor: high pressure drag
  → Backward pointing suction force on flap
- Overwing: induced thrust (neg. drag)



Aerodynamics – Overall Performance

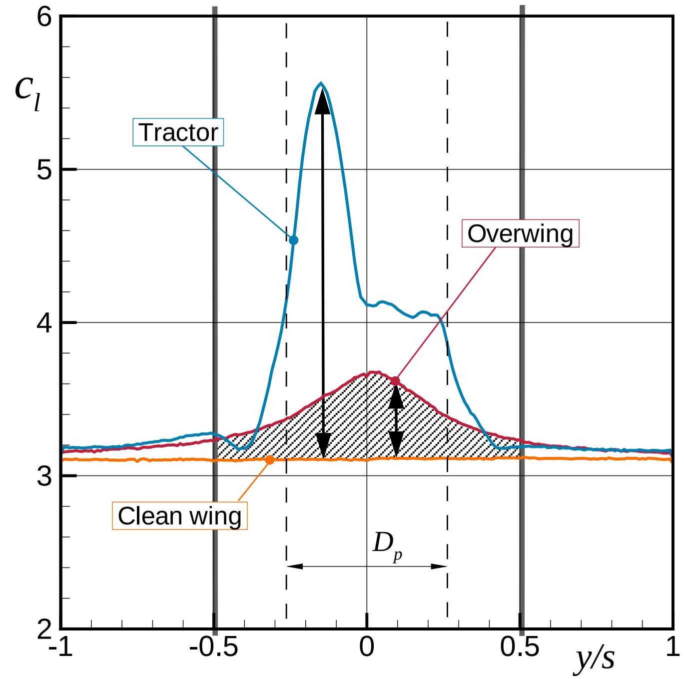
Aerodynamic balance

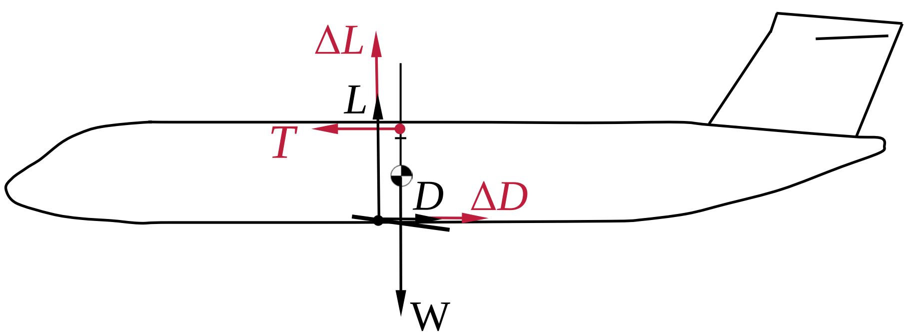
1. Calculate difference to clean wing
   → Propeller effekt
   → Transfer to a/c for ***y/s*** = -0.5…0.5
2. Integrate over this wing segment (span)
   → Propeller-induced delta forces (a/c)
3. Define L/D and T/W with aircraft data
   - $C_{L,ref} = 2.79$; $C_{D,ref} = 0.381$; m = 40 t

	Tractor	Over-wing
L / D	5.7	11.0
T / W	0.39	0.32
Climb angle*	12.6°	13.1°

* $\sin\theta = T/W - (L/D)^{-1}$

Aeroacoustic benefit

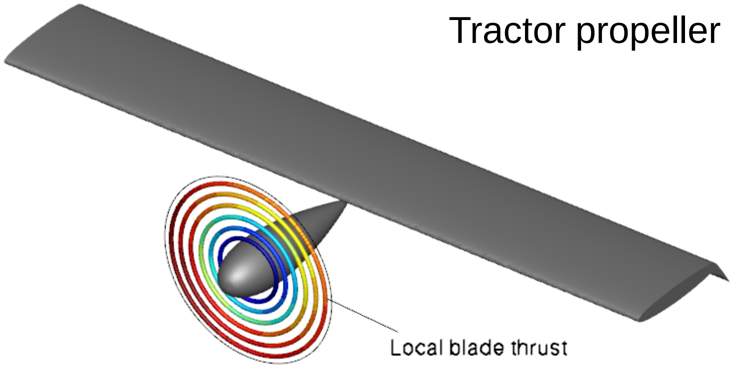




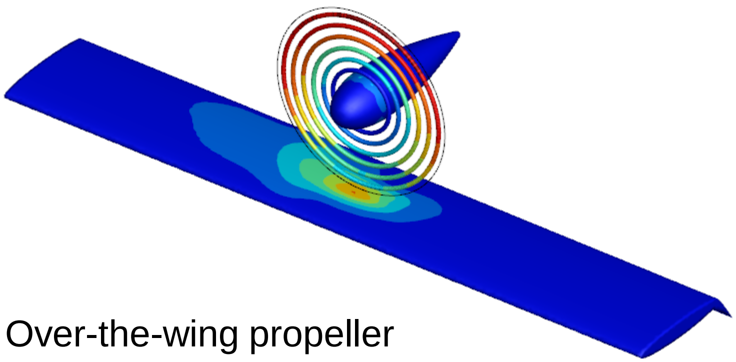
Aeroacoustics – Overwing

Actual propeller distribution

Meanflow not taken into account



Tractor propeller



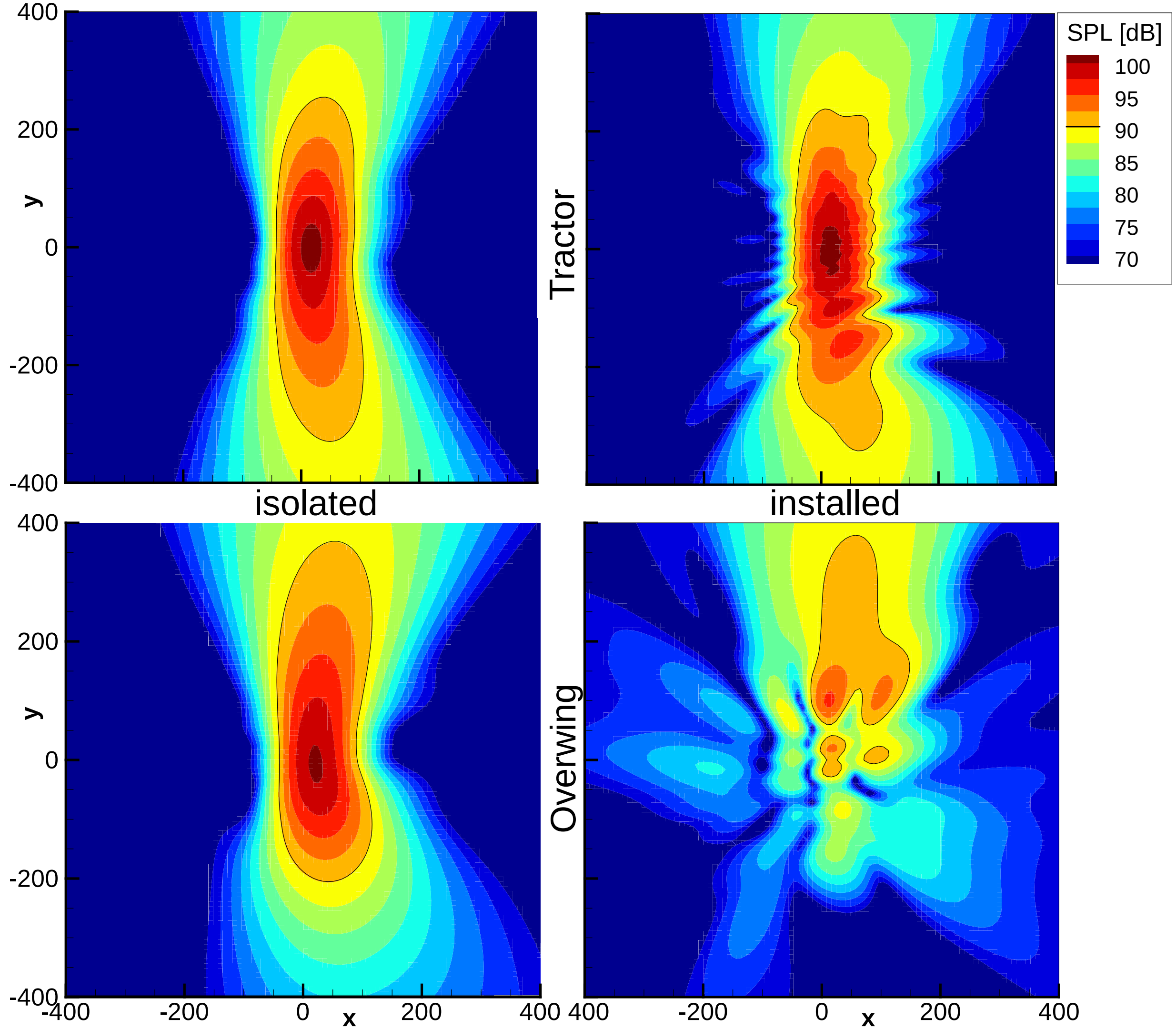
Over-the-wing propeller

Aeroacoustics – Overwing

Noise footprint

- H = 120 m, f = BPF
- 90 dB line highlighted

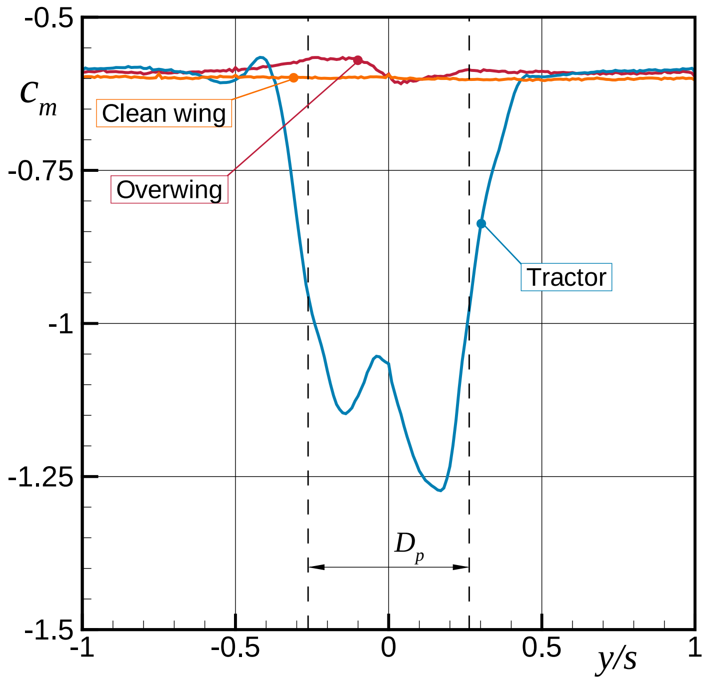
- Tractor
  - No shielding but interference
    (reflection, diffraction)
- Overwing
  - Different noise source due to thrust distribution
  - Asymmetric pattern
  - Different directivity
    - asymmetric
    - axial propagation
  - Shielding capability ~ 6 dB



Flight Dynamics – Pitching Moment

Balance of pitching moment (around C.G.)

- Integrate c_m (span), normalize with wing area and MAC of a/c → ΔC_M (wing)



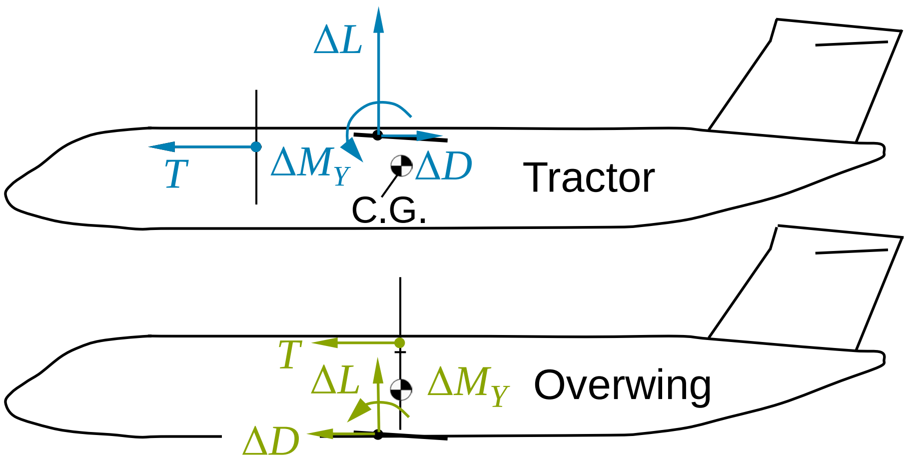
Wing pitching moment around aerodynamic center (1/4 c)

Flight Dynamics – Pitching Moment

Balance of pitching moment (around C.G.)

- Integrate c_m (span), normalize with wing area and MAC of a/c → ΔC_M (wing)
- List all forces and lever arms → pitching moment due to propeller installation

	Tractor	Over-wing
Wing (ΔC_M, ΔC_L, ΔC_D)	-0.08	0.13
Propeller (C_T)	-0.17	-0.44
Total $\Delta C_{M,y}$	-0.25	-0.31



Flight Dynamics – Pitching Moment

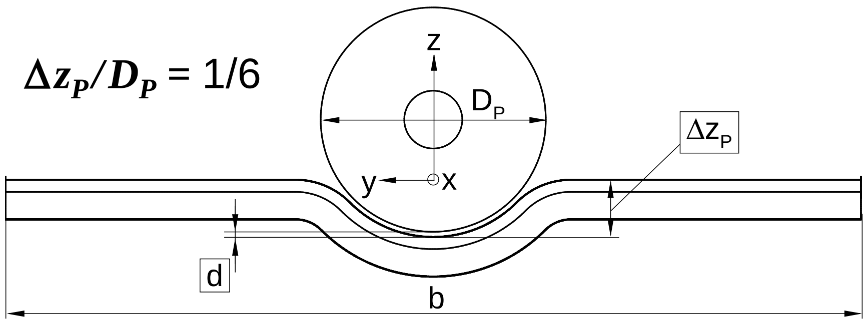
Balance of pitching moment (around C.G.)

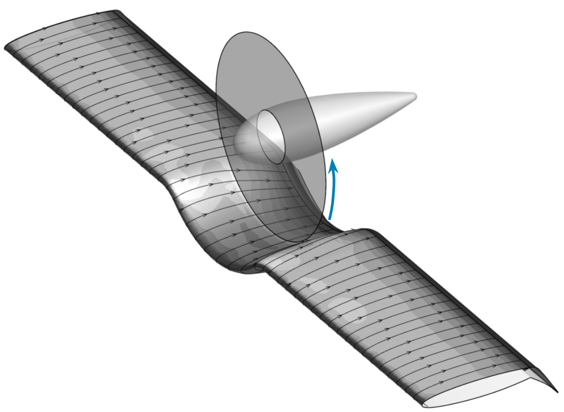
- Integrate c_m (span), normalize with wing area and MAC of a/c → ΔC_M (wing)
- List all forces and lever arms

	Tractor	Over-wing	Channel wing
Wing (ΔC_M, ΔC_L, ΔC_D)	-0.08	0.13	0.12
Propeller (C_T)	-0.17	-0.44	-0.23
Total $\Delta C_{M,y}$	-0.25	-0.31	-0.11
L / D	5.7	11.0	10.9
T / W	0.39	0.32	0.31
Climb angle	12.6°	13.1°	12.9°

+ ΔC_L = 0.1

$\Delta z_P / D_P$ = 1/6

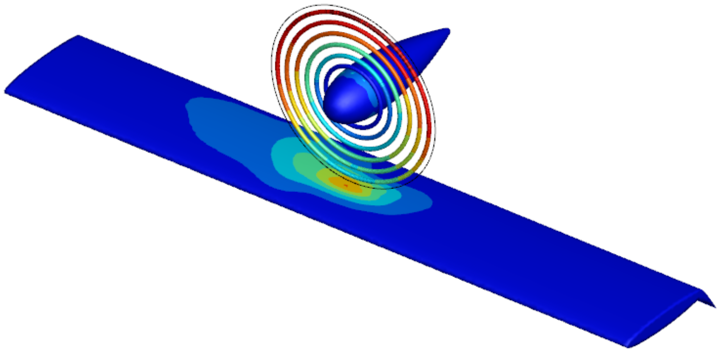


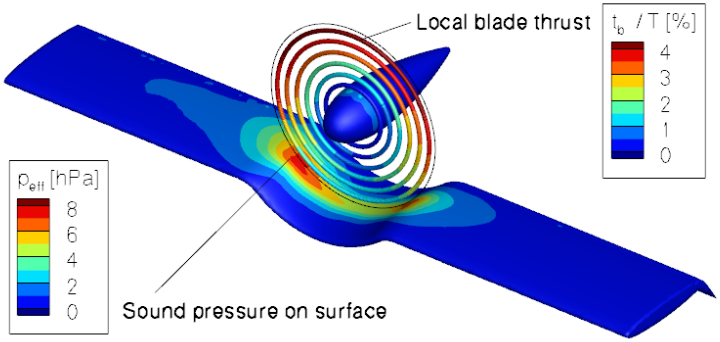


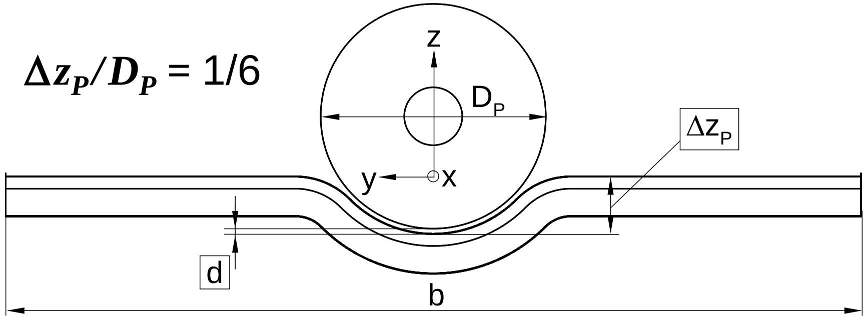
Aeroacoustics – Channel Wing

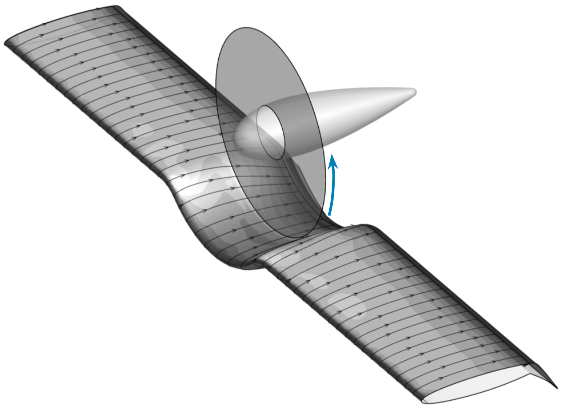
Sound pressure on wing surface

- Higher magnitude and larger patch for channel wing







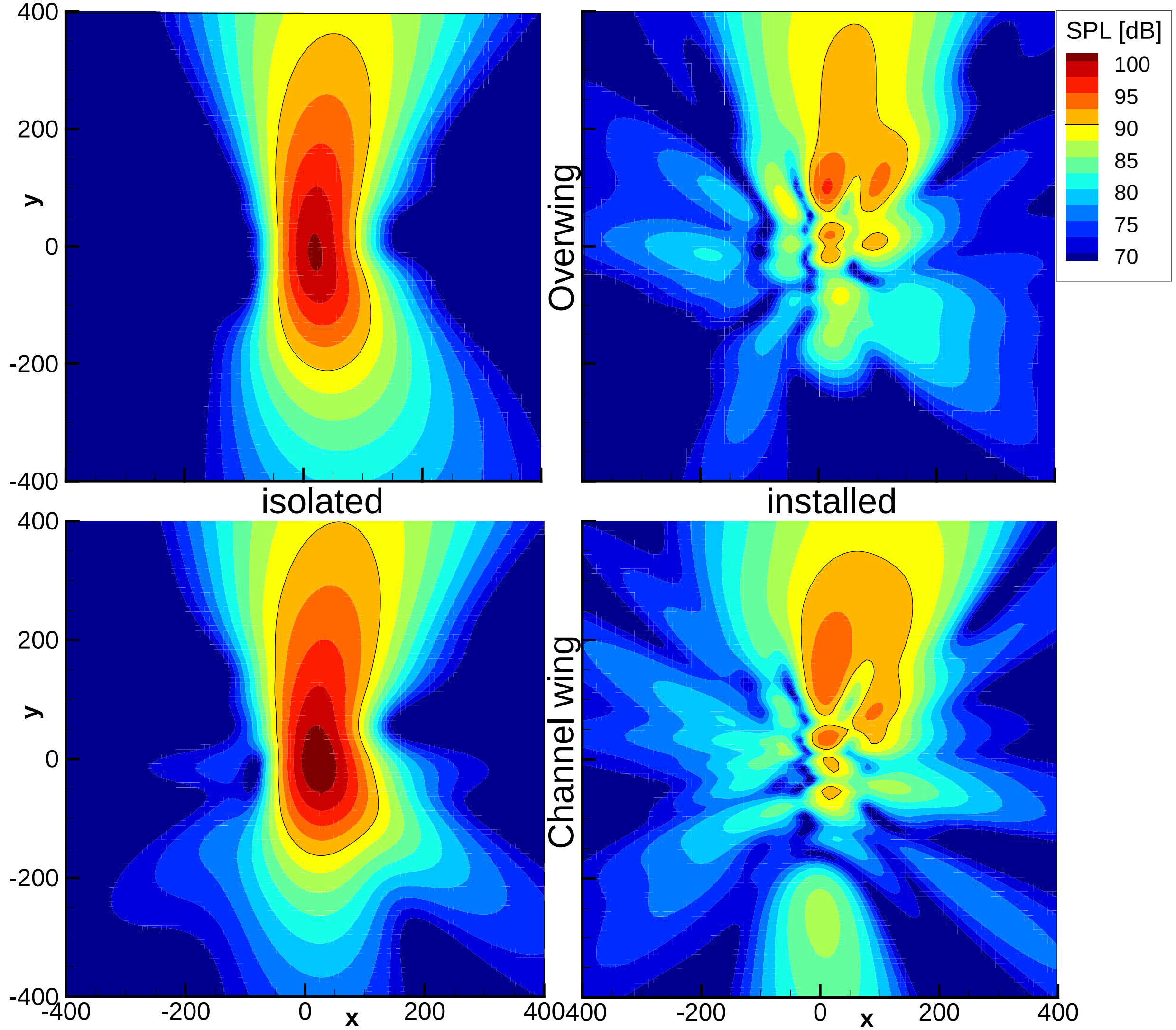


Aeroacoustics – Channel Wing

Noise footprint

- H = 120 m, f = BPF
- 90 dB line highlighted

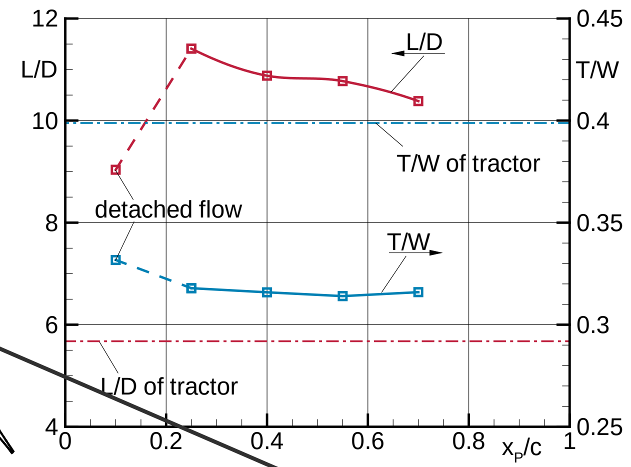
- Channelwing
  - Higher source magnitude
  - Slightly smaller footprint magnitude (larger patch)

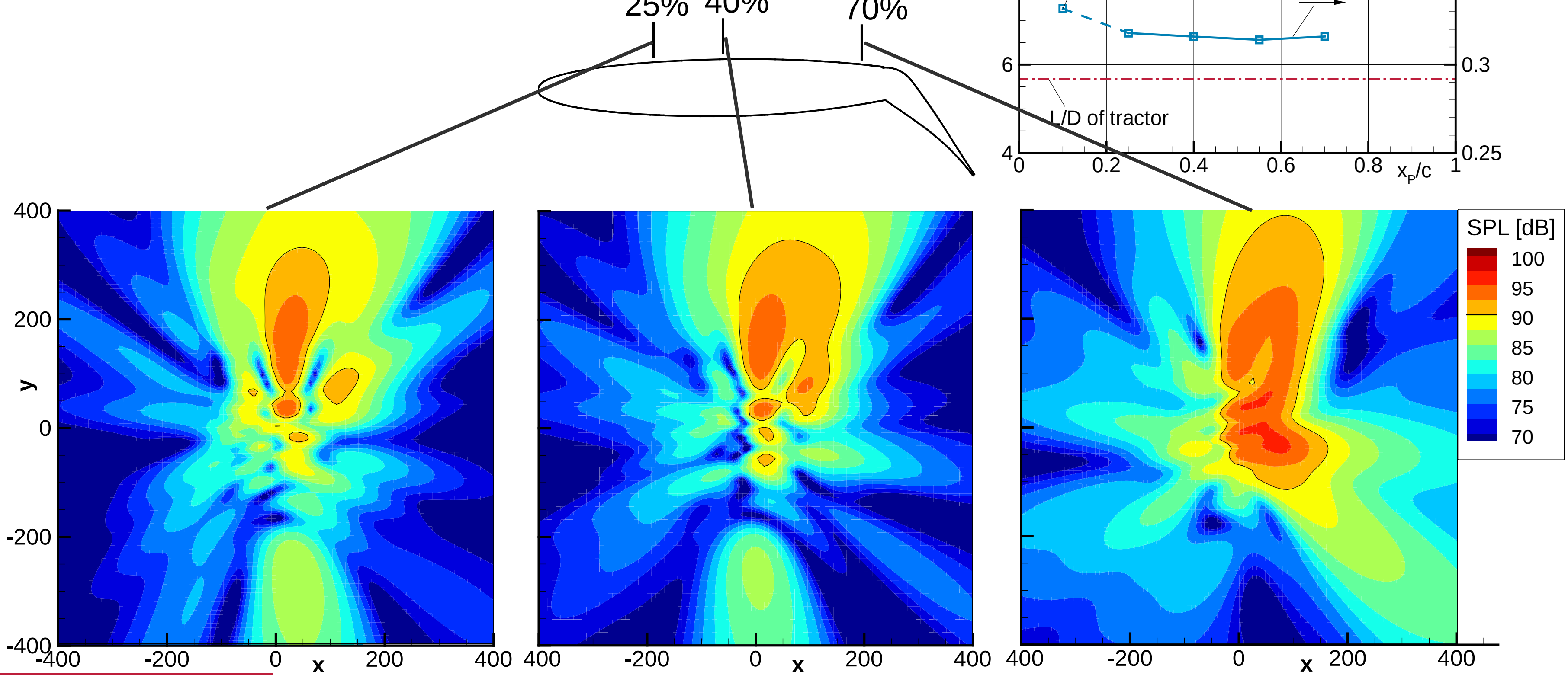


Influence of Axial Propeller Position

Influence of axial propeller position

- Best aerodynamics (climb angle) for x_P/c = 25%
- Best shielding also for this position





Conclusion and Outlook

Overwing vs. tractor

- Aerodynamics: Comparable climb angle
- Aeroacoustics: 6 dB noise reduction through shielding
- Flight dynamics: Channel wing reduces pitching moment

Channel wing aeroacoustics

- Similar shielding capabilities (compared to overwing)
- Axial prop. position between 25% and 40% favorable

Outlook

- Unsteady CFD and CAA
- Cruise condition
- Propeller redesign

Thank you for your attention.

Questions?

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